Mass Profiles and Shapes of Cosmological Structures
G. Mamon, F. Combes, C. Deffayet, B. Fort (eds)
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INTRACLUSTER STARS TRACING MOTIONS IN NEARBY CLUSTERS

Arnaboldi, M.[1]

Abstract. Cosmological simulations of structure formation predict that galaxies are dramatically modified by galaxy harassment during the assembly of galaxy clusters, losing a substantial fraction of their stellar mass which today must be in the form of intracluster stars. Simulations predict non-uniform spatial and radial velocity distributions for these stars. Intracluster planetary nebulae are the only abundant component of the intracluster light whose kinematics can be measured at this time. Comparing these velocity distributions with simulations will provide a unique opportunity to investigate the hierarchical cluster formation process as it takes place in the nearby universe.

1 Introduction

The intracluster light (ICL) in clusters contains a fossil record of galaxy evolution and interactions in the cluster. It is also relevant for the baryonic fraction condensed in stars, star formation efficiency, and the metal enrichment of the hot intracluster (IC) medium via IC stars, especially in the cluster center.

The high resolution simulation of a part of the Universe that collapses into a galaxy cluster shows that dark matter subhalos grow, fall into the cluster, may survive or merge into larger halos (Springel et al. 2001): the same processes may in fact act on stars in galaxies, producing also ICL. Simulations predict non-uniform spatial and radial velocity distributions for these stars (Napolitano et al. 2003) and the intracluster planetary nebulae (ICPNe) are the best suited tracers for these studies because of their strong [OIII] 5007 Å emission, which allow an easy identification and radial velocity measurements. Measuring the projected phase-space for the ICPNe allows us to determine the dynamical age of this component, how and when this light originated.

[1] INAF, Osservatorio Astronomico di Torino, Strada Osservatorio 20, I-10025 Pino Torinese

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2 ICPNe in the Virgo cluster: projected phase-space distribution

2.1 Results from narrow band imaging surveys

Based on the analysis done by Aguerri et al. (2005), the mean surface brightness and surface luminosity density of the ICL in several pointings in the Virgo cluster core fields are $\mu_B = 29.0$ mag arcsec^{-2} and 2.7×10^6 $L_{B,\odot}$ arcmin^{-2}, respectively. These values are in good agreement with the corresponding values obtained from excess red giant counts in two HST images in the Virgo core. There is no trend evident with distance from M87. When the fraction of the ICL is computed for the fields in the Virgo core, it amounts to 5% of the total galaxy light.

However, the diffuse stellar population in Virgo is inhomogeneous on scales of $30 - 90$ arcmin: substantial field-to-field variations are observed in the number density of PNe and the inferred amount of ICL, with some fields empty, some fields dominated by extended Virgo galaxy halos, and some fields dominated by the true IC component. Furthermore, the qualitative match between the luminosity density traced by ICPNe and the broadband light detected in the Virgo core by Mihos et al. (2005) argues that ICPNe are effective tracers of the ICL in galaxy cluster.

2.2 Results from spectroscopic surveys

Radial velocities of 40 ICPNe in the Virgo cluster were obtained with the new multifiber FLAMES spectrograph on UT2 at the VLT by Arnaboldi et al. (2004). For the first time, the λ 4959 line of the [OIII] doublet is seen in a large fraction (50%) of ICPNe spectra, see Fig. 1. Overall, these velocity measurements confirm the view that Virgo is a highly non-uniform and unrelaxed galaxy cluster, consisting of several subunits that have not yet had time to come to equilibrium in a common gravitational potential, as shown in the velocity histograms of Fig. 2.

A well-mixed IC stellar population is seen clearly only in the CORE field, in the outer parts of the M87 subcluster. Here the velocity distribution is consistent with a single cluster Gaussian, and the ICPNe might well have their origin in the tidal effects of the halo of this subcluster on its galaxy population. In the SUB field near M84 and M86, the ICPNe do not appear virialized; their velocities are highly correlated with those of the large galaxies in the field. In fact, there are regions in Virgo where hardly any ICPNe are found, as in the LPC field of Aguerri et al. (2005). The measurements have also shown that M87 has a very extended envelope in approximate dynamical equilibrium, reaching out to at least 65 kpc.

The field-to-field variations, both in number density and in velocities, indicate that the ICL is not yet dynamically mixed. This imposes a constraint on the time of origin of the ICL and the Virgo cluster itself. The lack of phase mixing suggests that both have formed in the last few gigayears and that local processes like galaxy interactions and harassment have played an important role in this. In a cluster as young and unrelaxed as Virgo, a substantial fraction of the ICL may still be bound to the extended halos of galaxies, whereas in denser and older clusters these halos might already have been stripped.

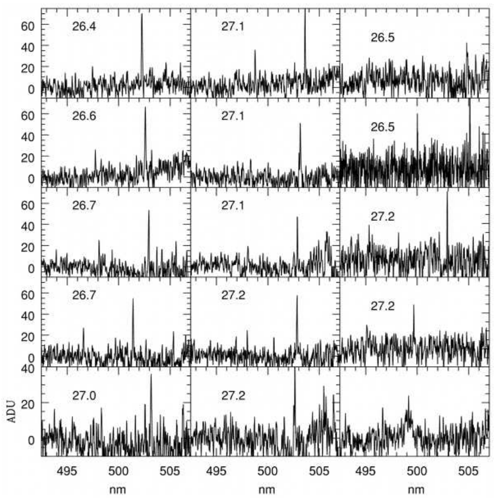

Fig. 1. FLAMES spectra for 14 ICPNe observed different field position in the Virgo cluster core. The spectrum in the lower right corner is a Lyα object, which shows a very broad line profile. The $m_{(5007)}$ magnitudes are marked on the individual frames. From Arnaboldi et al. (2004).

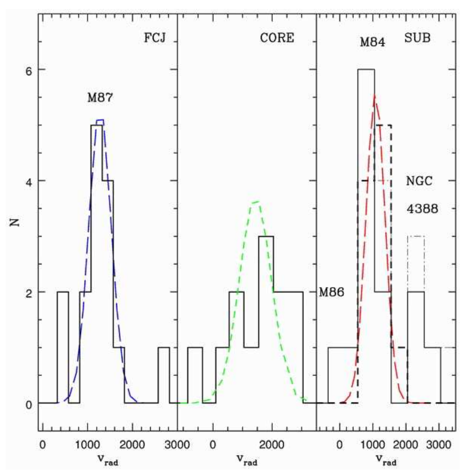

Fig. 2. ICPN radial velocity distributions in the three pointings (FCJ, CORE, and SUB) from Arnaboldi et al. (2004).

3 ICPNe in the Coma cluster: first detections and future prospects

The Coma cluster is the richest and most compact of the nearby clusters, where the effect of a dense environment on galaxy evolution can be studied. Despite

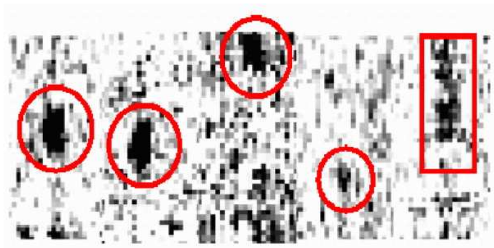

Fig. 3. Two-dimensional median-averaged spectra of emission objects in the MSIS field. The wavelength is along the vertical axis (507.7-514.15 nm) with a rebinned resolution of 1.5 Å pixel^{-1}; the true spectral resolution is 7.3 Å or 440 km s^{-1}. The horizontal direction is along the mask slitlets, with a rebinned resolution of $0''.2$ pixel^{-1}. The left four panels show PN candidates from the brightest to one of the faintest in the field. The fluxes are (34.7, 31.9, 18.6, 5.6) ADU, corresponding to (17, 16, 9, 3) 10-19 ergs s^{-1} cm^{-2}. The rightmost panel shows the spectrum of a background galaxy with continuum and strong absorption, probably blueward of Lyα, and a possible line emission, probably Lyα. From Gerhard et al. (2005).

being the most compact, there is growing evidence that its formation is still ongoing, and needs to be investigated further. This is now becoming possible via a multislit imaging spectroscopy technique (MSIS) using spectrographs on 8 meter class telescopes. Gerhard et al. (2005) measured the [O III] $\lambda5007$ emission lines of 16 ICPN candidates in the Coma cluster with MSIS and FOCAS, on the 8.2 m Subaru telescope; the two-dimensional median-averaged spectra of their emission objects in the MSIS field are shown in Fig. 3. Comparing with the velocities of Coma galaxies in the same field, Gerhard et al. (2005) conclude that the great majority of these candidates would be ICPNe, free floating in the Coma cluster core. The velocity histogram for the full sample of ICPN in the MSIS Coma field in now showing presence of substructures (Arnaboldi et al. in prep.), with the second low velocity peak which may originate from material of the low-velocity G7 group of galaxies (Adami et al. 2005).

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